Pasture Management Influences on Soil Properties in the Northern Great Plains

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ABSTRACT: The effect of management practices associated with livestock grazing on soil properties are largely unknown. Several physical, chemical, and biological soil properties were compared for soil from a native vegetation exclosure, a moderately grazed native vegetation pasture stocked at 2.6 ha (6.4 ac) steer^{-1}, a heavily grazed native vegetation pasture stocked at 0.9 ha steer^{-1}, and a fertilized crested wheatgrass (Agropyron cristatum L. Gaertn.) pasture stocked at 0.9 ha steer^{-1} near Mandan, North Dakota. The three native vegetation pastures were established in 1916 and the crested wheatgrass pasture was seeded in 1932. Soil properties varied in sensitivity to the management practices. Measures of vegetation and animal production, combined with assessment of soil properties suggest that moderate grazing and fertilization of crested wheatgrass are viable management options that appear to be sustainable while providing goods and services needed by society. Range and pasture assessment should include soil assessment to more completely determine management effects on pastoral ecosystems.

Keywords: Grazing management, microbe numbers, mixed grass prairie, N mineralization, North Dakota, organic C, soil quality

Livestock grazing is an integral part of many agricultural operations in the Northern Great Plains. The mixed grass prairie common to this region provides good quality forage during the growing season. Concerns regarding the proper management of mixed grass prairie resulted in the establishment of grazing trials in the early 1900s. These trials determined that moderate grazing (grazing that removes about 50% of the aboveground dry matter produced) was sustainable, resulting in good animal performance while maintaining prairie vegetation (Rogler 1951). However, grazing too early in the growing season was detrimental to the mixed grass prairie vegetation and resulted in reduced productivity and a shift, to less desirable forage species, in the species composition.

Cool season introduced grasses have been used to extend the growing season and provide early forage (Rogler and Lorenz 1969). Crested wheatgrass (Agropyron cristatum L. Gaertn.) has been planted on extensive acreages in the Northern Great Plains and is well adapted to conditions of this region, having been introduced from the steppe region of Russia in 1898 and 1906 (Rogler and Lorenz 1983). Crested wheatgrass has higher water use efficiency than intermediate wheatgrass (A. intermedium Beauv.) or western wheatgrass (Pascopyrum smithii (Rybd) Löve), yields more and is more digestible than western wheatgrass, but has a similar digestibility and is lower yielding than intermediate wheatgrass (Frank and Karn 1988). Acceptable live weight gains have been reported for steers grazing crested wheatgrass throughout the season (Hofmann et al. 1993).

Soils perform many ecosystem functions. Soil serves as a substrate for plant growth, as a reservoir for many nutrients, as a filter maintaining air quality through interactions with the atmosphere, as a storage and purification medium for water as it passes through the soil, and as a biological reactor serving as the site for decomposition and recycling of animal and plant products.

Because of the multiple functions of soil, interest in soil quality (health) has increased in recent years. Soil quality has been defined as: "the capacity of a soil to function, within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health" and key soil properties have been suggested as indicators of soil quality (Doran and Parkin 1994, p 7). Much of the research regarding soil quality has been conducted in intensively managed cropland systems. As interest in the C sequestration potential of range and pasture land increases, studies assessing the effect of management on soil properties in pasture land will be needed.

Long term grazing trials provide an opportunity to assess the effect of management practices on various soil properties. In 1916 a grazing trial was initiated near Mandan, North Dakota to assess the effects of grazing intensity on mixed grass prairie vegetation and animal performance. In 1932, a fertilized crested wheatgrass pasture was established adjacent to this grazing trial to determine the potential of this species to increase the length of the grazing season and to provide high quality forage. Unfortunately, like many grazing experiments established during this time period, the grazing trial at Mandan is unreplicated. While this constrains statistical analysis, the long term treatments and annual animal and vegetation production data (e.g., Sarvis 1941), which continues to be collected, make such sites unique and of value for studying vegetation dynamics, C sequestration, and soil quality.

Animal performance (Hofmann et al. 1993), vegetation dynamics (Frank et al. 1998), and C and N contents of these soils (Frank et al. 1995) have been reported from grazing trials at Mandan. Comparison of C and N content in soils of the long term native pastures indicated that C content was lower in soils of the moderately grazed pasture than in soils of the ungrazed or heavily grazed pastures, and N content was lower in soils of both grazed pastures than in the ungrazed exclosure (Frank et al. 1995). The effect of pasture management on other soil properties has not been reported.

The objective of the present study was to compare physical, chemical, and biological soil properties from soils in a long term grazing trial consisting of an ungrazed native exclosure, a moderately grazed native pasture, a heavily grazed native pasture, and a fertilized crested wheatgrass pasture. Differences in soil properties were combined with animal performance and forage production data and used to assess the sustainability of the various management practices.

Materials and Methods

Study site. The field site was located in Morton County 3.2 km south of Mandan (46° 46' N 100o 50' W, elevation 549 m above sea level). Soils at the site are a Temvik-Wilton silt loam (fine-silty, mixed Typic, and Pachic Haploborolls). Annual precipitation is highly variable and averages 410 mm with 60% received during the

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Table 1. Summarization of differences in pasture management and species composition.

Pasture	Stocking ha steer^{-1}	Fertilizer kg ha^{-1}	Dominant Forage Species
Exclosure	0	0	*Carex filifolia, C. heliophila, and Poa pratensis*
Moderately grazed	2.6	0	*Bouteloua gracilis, Stipa comata, Koelaria pyramidata*
Heavily grazed	0.9	0	*B. gracilis*
Crested Wheatgrass	0.9	44.8	*Agropyron cristatum*

growing season of April to October. Average annual temperature is 4° C (39° F) and daily averages range from a maximum of 21° C (70° F) during the summer to a minimum of – 11° C (12° F) during the winter.

In 1916, native grass pastures were established and a grazing trial comparing moderate grazing to heavy grazing was initiated. An exclosure was established as a control in the moderately grazed pasture. In 1932, an additional pasture was created, planted to crested wheatgrass, and fertilized annually at a rate of 44.8 kg ha^{-1} of N as NH_4NO_3. The class of livestock used in the grazing study has varied over the years, but from 1987 to 1997 the pastures have been grazed 'season-long' (continuous grazing generally from early June to early October) by yearling steers. For the last ten years, the fertilized, crested wheatgrass pasture has been stocked at a rate of 0.9 ha steer^{-1}, the heavily grazed native pasture has been stocked at a rate of 0.9 ha steer^{-1}, and the moderately grazed native pasture has been stocked at a rate of 2.6 ha steer^{-1}. During 1988 and 1990, drought reduced forage production in the fertilized crested wheatgrass and heavily grazed pastures below that necessary to support livestock grazing and steers were not placed in these pastures.

When this grazing trial was initiated, the vegetation in the two native grassland pastures was similar with blue grama (Bouteloua gracilis (H.B.K.) Lab. Ex Griffiths), needle-and-thread (Stipa comata Trin. and Rupr.), western wheatgrass, and prairie junegrass (Koelaria pyramidata (Lam) Beauv.) dominating the stands. In 1994, the species composition in the moderately grazed pasture was similar to that in 1918 except that sedges (Carex filifolia Nutt. and C. heliophila Mack.) and Kentucky bluegrass (Poa pratensis L.) has become established. In the heavily grazed pasture, blue grama had increased and needle-and-thread, western wheatgrass, and prairie junegrass had essentially disappeared. In the exclosure, blue grama was replaced by sedges and Kentucky bluegrass with needle-and-thread present as a minor component.[1]

In October 1997, five sites were located within each pasture that had similar slopes and exposure. Within these sites, soil samples were collected at five random points from the 0–5 cm and 5–15 cm depths. Preliminary sampling demonstrated that five samples were sufficient to describe the variation present at these sites.

Laboratory methods. Soils were passed through a 4 mm sieve to remove root material, soil mass was recorded, and moisture content was determined. Soils were stored at – 5° C (23° F) until biological properties were assessed. After assessment of biological properties, the remaining soil was passed through a 2 mm sieve, air dried, ground, and used for chemical analyses.

Bulk density was the only physical soil property measured. Bulk density was calculated by dividing the mass of soil, corrected for moisture content, by the volume of soil collected (Blake and Hartge 1986).

Total organic C, total N, inorganic N, pH, and electrical conductivity (EC) were the chemical properties measured. Total N and C were determined by dry combustion using a Carlo-Erba NA 1500 NCS analyzer (Carlo Erba Instruments, Milan, Italy). Carbonates were not present and total C was assumed to represent organic C. Inorganic N was measured in 0.01 mol L^{-1} $CaCl_2$ extracts colorimetrically using a Lachat flow injection ion analyzer (Zellweger Analytics, Lachat Instruments Division, Milwaukee, WI). Distilled water was added (1:1 on a gravimetric basis) to 10 g of air dried soil and pH determined using a glass electrode (McLean 1982). The soil slurry was then filtered and EC determined using a conductivity meter (Rhoades 1982).

Biological soil properties assessed included: N-mineralization; numbers of culturable fungi, bacteria, and actinomycetes; and microbial biomass C and N. Nitrogen mineralization rate was determined using a laboratory incubation method similar to that described by Stanford and Smith (1972). Silica sand and 15 g of soil were added together in equal amounts and thoroughly mixed. The mixture was transferred to a glass leaching tube and glass wool was placed on the soil surface to prevent dispersion of the sample during leaching. Every two weeks the tubes were leached with 100 ml of 0.01 mol L^{-1} $CaCl_2$ and returned to the incubator. Tubes were incubated for a total of eight weeks. Leachates were stored at – 5° C (23° F) until they could be analyzed for inorganic N content. Inorganic N content of leachate was determined by quickly thawing the samples and determining $N\text{-}NH_4$ and $N\text{-}NO_2$ plus $N\text{-}NO_3$ content by automated colorimetric analysis using a Lachat flow through ion analyzer (Zellweger Analytics, Lachat Instruments Division, Milwaukee, WI).

Fungi, bacteria, and actinomycete numbers were determined by plating a serial dilution of a soil-water suspension on selective media. Bacteria were grown out on tryptic soy agar, actinomycetes were grown out on starch-casein agar, and fungi were grown out on Martin's Rose Bengal agar (Wollum 1982).

Microbial biomass N and C were determined using the chloroform extraction method as modified by Bruulsema and Duxbury (1996). Both fumigated and nonfumigated soils were extracted with 50 ml of 0.05 mol L^{-1} K_2SO_4. Extracts were filtered into plastic bottles and stored at – 5° C (23° F) until analyzed for C and N using a Carlo-Erba NA 1500 NCS analyzer (Carlo Erba Instruments, Milan, Italy).

While these long term pastures are not replicated, we have followed the approach of Frank et al. (1995) and considered each of the five collection sites a replication for calculation of summary statistics. Each pasture was treated as a discrete variable and results are reported as means ± standard error of the mean. This approach is not ideal but there are few long term studies from which to collect this type of data and we feel this uniqueness justifies such an approach.

Results

Physical properties. Bulk density in the 0–5 cm depth was lowest in the ungrazed exclosure and greatest in the heavily grazed native pasture. The bulk density in the 0–5 cm depth soil of the fertilized crested wheatgrass pasture was similar to that of the moderately grazed native pasture (Table 2). Bulk density was similar among pastures (Table 2) and averaged 0.826 ± 0.031 g cm^{-3} in the 5–15 cm

Table 2. Physical and chemical soil properties under different grazing treatments.

Grazing Treatment	Bulk Density g cm^{-3}	pH	E. C. dS m^{-1}	N-NH$_4$ kg ha^{-1}	N-NO$_3$ kg ha^{-1}	N g kg^{-1}	C g kg^{-1}	N Mg ha^{-1}	C Mg ha^{-1}
	(0–5 cm)								
Ungrazed	0.39 ± 0.07[a]	6.3 ± 0.1	0.34 ± 0.02	0.28 ± 0.09	1.03 ± 0.27	4.93 ± 0.24	59.2 ± 3.4	0.84 ± 0.10	10.1 ± 1.3
Moderate	0.48 ± 0.06	5.9 ± 0.1	0.28 ± 0.01	0.90 ± 0.24	0.82 ± 0.14	4.23 ± 0.31	51.3 ± 4.5	1.00 ± 0.06	12.0 ± 0.6
Heavy	0.61 ± 0.07	6.3 ± 0.1	0.20 ± 0.01	0.24 ± 0.09	1.48 ± 0.38	3.94 ± 0.40	45.9 ± 4.7	1.16 ± 0.12	13.5 ± 1.4
Fertilized crested wheatgrass	0.42 ± 0.06	–[b]	–[b]	2.20 ± 1.40	0.94 ± 0.08	5.91 ± 0.62	67.5 ± 8.7	1.21 ± 0.09	13.7 ± 1.3
	(5–15 cm)								
Ungrazed	0.73 ± 0.07	6.1 ± < 0.1	0.20 ± 0.01	0.58 ± 0.14	1.93 ± 0.20	2.12 ± 0.11	25.0 ± 1.7	1.56 ± 0.14	18.4 ± 1.8
Moderate	0.88 ± 0.05	6.1 ± < 0.1	0.19 ± 0.02	1.78 ± 1.10	1.81 ± 0.36	1.98 ± 0.10	22.9 ± 1.3	1.76 ± 0.14	20.5 ± 1.7
Heavy	0.86 ± 0.07	6.3 ± < 0.1	0.27 ± 0.03	0.48 ± 0.20	4.40 ± 0.75	3.09 ± 0.25	36.4 ± 3.1	2.30 ± 0.14	26.9 ± 1.6
Fertilized crested wheatgrass	0.84 ± 0.03	–[b]	–[b]	1.10 ± 0.32	5.82 ± 0.38	2.61 ± 0.11	30.2 ± 1.3	2.23 ± 0.16	25.8 ± 1.9

[a] Mean ± Standard Error of the Mean.
[b] pH and EC not determined.

depth. The bulk density values observed in the 0–5 cm depth were lower than expected and was likely the result of the high organic matter content, presence of numerous plant crowns, and extensive shallow root systems present in the blue grama dominated perennial vegetation of these pastures. The increase in bulk density as grazing pressure increased suggests that the surface soils are being compacted by trampling, with compaction greater in the heavily grazed pasture.

Chemical properties. In the 0–5 cm depth, pH was lower in the moderately grazed pasture than in ungrazed or heavily grazed pastures (Table 2). In the 5–15 cm depth, pH was lower in ungrazed and moderately grazed pastures than in the heavily grazed pasture (Table 2). Insufficient soil was collected from the crested wheatgrass pasture to determine pH and EC. Except for differences in species composition among the pastures, there is no apparent reason for the observed differences in pH and the magnitude of the differences (0.4 pH units in the surface layer and 0.2 pH units in the lower depth) is modest. The pH of soils in this study are within the optimum range for plant growth and microbial activity. Electrical conductivity decreased with grazing intensity in the 0–5 cm depth (Table 2). Electrical conductivity was similar across pastures in the 5–15 cm depth. The EC of the soils in the present study are representative of non saline soils under perennial vegetation.

Inorganic N (N-NH$_4$ and N-NO$_3$) contents were similar among the pastures in the 0–5 cm depth (Table 2). In the 5–15 cm depth, N-NH$_4$ content was similar among the pastures but N-NO$_3$ content was greater in the heavily grazed and crested wheatgrass pastures than in the ungrazed or moderately grazed pastures (Table 2). With fertilization or heavy grazing, N-NO$_3$ accumulated slightly at the lower depths of these pastures. The increase in inorganic N with heavy grazing may be due to residual N excreted in urine and dung. In the crested wheatgrass pasture, fertilizer applied annually most likely contributed to the increase in inorganic N. Soil N-NO$_3$ content was similar or greater than N-NH$_4$ for both depths in all pastures (Table 2) suggesting that nitrifying bacteria were active in these soils. In spite of the treatment effects noted above, inorganic N concentrations were relatively low in all pastures, suggesting that there is little potential for leaching loss of N-NO$_3$ in these pastures.

Total N concentration in the 0–5 cm depth was highest in the crested wheatgrass pasture and lowest in the heavily grazed pasture (Table 2). Organic C concentration in the 0–5 cm depth exhibited a similar pattern to that of total N. When nutrient concentration is multiplied by bulk density and expressed on an areal basis, C and N content in the 0–5 cm depth was highest in the heavily grazed and crested wheatgrass pastures and lowest in the exclosure (Table 2). In the 5–15 cm depth, N and C concentrations and contents were greater in the heavi-

Table 3. Biological properties of soil under different grazing treatments.

Grazing Treatment	N-Mineralization kg ha^{-1} week^{-1}	Fungi 10^7 m^{-2}	Actinomycetes 10^{10} m^{-2}	Bacteria 10^{10} m^{-2}
	(0–5 cm)			
Ungrazed	0.78 ± 0.21	14.3 ± 1.9	5.8 ± 1.6	8.7 ± 2.5
Moderate	1.33 ± 0.37	12.0 ± 2.7	7.0 ± 3.8	8.4 ± 0.3
Heavy	1.07 ± 0.49	7.9 ± 1.3	5.4 ± 0.7	4.5 ± 0.5
Fertilized crested wheatgrass	8.37 ± 0.46	12.1 ± 3.1	1.9 ± 0.5	5.6 ± 1.8
	(5–15 cm)			
Ungrazed	3.69 ± 1.06	15.5 ± 2.5	5.8 ± 1.3	11.9 ± 1.9
Moderate	5.60 ± 0.24	9.8 ± 1.4	4.8 ± 1.0	5.0 ± 1.2
Heavy	6.82 ± 0.95	17.3 ± 3.5	13.4 ± 2.9	15.5 ± 2.8
Fertilized crested wheatgrass	8.58 ± 0.99	20.2 ± 4.4	9.8 ± 1.8	8.7 ± 1.9

ly grazed and crested wheatgrass pastures than in the moderately grazed pasture or the exclosure (Table 2).

Biological properties. Very little NH_4 was present in the N-mineralization leachates. Therefore, NH_4 was combined with NO_2 and NO_3 to give total N mineralized. Release of inorganic N was found to be linear with time. Mineralization rates were calculated using linear regression and ranged from 0.5–60.2 μg g^{-1} wk^{-1} with coefficients of determination ranging from 0.85–0.99. Nitrogen mineralization rates in the 0–5 cm depth were similar among the native pastures and were highest in the crested wheatgrass pasture (Table 3). In the 5–15 cm depth of the native grass pastures, N-mineralization rates were lowest in the ungrazed pasture and greatest in the heavily grazed pasture. Nitrogen mineralization rates in the 5–15 cm depth were highest in the crested wheatgrass pasture, probably because fertilizer N becomes immobilized in soil organic matter that is more mineralizable than mature soil organic N present in the native grass pastures (Table 3).

Numbers of culturable microorganisms in the 0–5 cm depth soil were similar among the soils (Table 3). In the 5–15 cm depth; fungi numbers were similar among the pastures while bacteria and actinomycete numbers were greater in the heavily grazed pasture than in the other three pastures (Table 3). Microbial biomass C was similar among the pastures and averaged 322 ± 21 kg ha^{-1} in the 0–5 cm depth and 348 ± 36 kg ha^{-1} in the 5–15 cm depth. Microbial biomass N was similar among the pastures and averaged 18 ± 2 kg ha^{-1} in the 0–5 cm depth and 31 ± 7 kg ha^{-1} in the 5–15 cm depth. The microbial biomass C to soil organic C ratio of 0.024 ± 0.002 in the 0–5 cm depth and 0.014 ± 0.001 in the 5–15 cm depth and microbial biomass N to soil organic N ratio of 0.016 ± 0.002 in the 0–5 cm depth and 0.017 ± 0.004 in the 5–15 cm depth was similar among the pastures.

Discussion

Results from this study suggest that physical, chemical, and biological soil properties vary in sensitivity to the effects of grazing management. Several chemical properties (e.g., pH, EC, inorganic N content) and biological properties (e.g., fungi numbers, microbial biomass N and C) were not affected by the management practices used in this study. Grazing intensity affected bulk density with increased trampling at higher stocking rates increasing bulk density. Grazing intensity also affected species composition in the native pastures.

Since 1916, there has been a decline in blue grama and an increase in sedges and Kentucky bluegrass in the ungrazed exclosure; an increase in sedges and Kentucky bluegrass in the moderately grazed pasture; and a large increase in blue grama in the heavily grazed pasture (Frank et al. 1995). The changes in species composition in the native pastures that resulted from differences in grazing pressure and differences in nutrient and organic inputs likely changed the amount and distribution of organic matter entering the soil. Lorenz and Rogler (1967) reported greater root production in the surface 30 cm of the heavily grazed pasture compared to the other pastures. In the native pastures, total N content, organic C content, and N-mineralization rate increased as the bulk density and the amount of blue grama in the stand increased. Holland and Detling (1990) also reported higher N mineralization rates in grazed than in ungrazed native prairie.

In the fertilized, crested wheatgrass pasture, total N, organic C, and N-mineralization rates were maintained at higher levels than those in the native grass pastures, most likely due to the annual inorganic fertilizer N additions resulting in a lower C:N ratio in this soil and to differences in quality (e.g., C:N ratio, lignin content) between roots of crested wheatgrass and roots of native grasses (Herman et al. 1977).

The number of culturable actinomycetes and bacteria tended to be higher in the heavily grazed pasture. In the present study there is a trend for culturable actinomycete and bacteria to be greater in heavily grazed pasture than in the fertilized crested wheatgrass pasture. The effect of grazing and replacement of native species with fertilized crested wheatgrass on soil microorganisms appears to be best explained by differences in below ground vegetation production among the pastures. Power (1980) reported lower root production and higher above ground dry matter production by crested wheatgrass than native prairie and Klein et al. (1988) have reported greater microbial activity in the rhizosphere of blue grama than in crested wheatgrass.

Previous researchers concluded that moderate grazing of the mixed grass prairie was sustainable (Rogler 1951). Rogler based his assessment of sustainability of these grazing treatments on maintenance of the mixed grass prairie vegetation, vegetation production, and animal performance. Comparison of soil properties under these management practices suggests that moderate grazing sustains the soil resource as well. Soil in the moderately grazed pasture was not compacted to the degree that soil in the heavily grazed pasture was and C content, N content, and N-mineralization rates in the moderately grazed pasture are comparable or greater than those in the ungrazed exclosure. Since the mixed grass prairie evolved under grazing, it is reasonable that nutrient content and mineralization rates would be maintained under moderate grazing.

In contrast, heavy grazing results in a change in species composition and a reduction in forage and animal production (Table 4). Likewise, ungrazed pasture can potentially provide other goods and services needed by society (water, wildlife, and recreation) but moderately grazed mixed grass prairie has been shown to perform these functions as well (Sedivec et al. 1990). Since the mixed grass prairie evolved under grazing pressure, the trend for lower C and N content and the shift in species composition observed in the exclosure suggest that exclusion from grazing may not be desirable.

Comparison of animal performance and forage production (1987 to 1997) between fertilized, crested wheatgrass pasture, and the native pasture suggests that conversion of native vegetation to fertilized tame pasture is also a viable management practice (Table 4). At the stocking rate used in this study, bulk density in the fertilized, crested wheatgrass pasture was

Table 4. Forage production and livestock performance (average from 1988 to 1998) as a function of grazing treatment.

Grazing Treatment	Forage Production kg ha^{-1}	Animal Gain kg $animal^{-1}$	Animal Gain kg ha^{-1}
Moderate	4260 ± 456[a]	131 ± 16	20 ± 3
Heavy	2030 ± 204	97 ± 25	42 ± 11
Fertilized crested wheatgrass	4090 ± 491	86 ± 15	75 ± 19

[a] Mean ± standard error of the mean.

similar to that in the moderately grazed pasture. Also, annual N fertilization maintained the N and C content of soils in this pasture at levels similar to or greater than that in the moderately grazed pasture.

Conclusion

Soil quality is only one measure of ecosystem health and is most useful when combined with other ecosystem attributes. In the present study, soil properties were combined with plant and animal performance to assess pasture management practices. Moderate grazing of native mixed grass prairie maintains the vegetation, results in acceptable animal production, and does not degrade the soil resource. Fertilized, crested wheatgrass provides season-long grazing, acceptable animal production, and does not degrade the soil resource. Both grazing systems are ecologically sustainable and the choice of which system to use should be based on economics and which practice best fits into a producer's crop livestock system.

Our results show that assessment of soil properties compliments any assessment of ecosystem function and should be included when comparing management practices.

ENDNOTES

[1] Pasture management practices and forage composition are summarized in Table 1.

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